

# 1. Cascadia: Oregon’s Greatest Natural Threat

## Introduction

When, not if, the next great Cascadia subduction zone earthquake strikes the Pacific Northwest, Oregon will face the greatest challenge in its history. Oregon’s buildings, transportation network, utilities, and population are simply not prepared for such an event. Were it to occur today, thousands of Oregonians would die, and economic losses would be at least \$32 billion. In their current state, our buildings and lifelines (transportation, energy, telecommunications, and water/wastewater systems) would be damaged so severely that it would take three months to a year to restore full service in the western valleys, more than a year in the hardest-hit coastal areas, and many years in the coastal communities inundated by the tsunamis. Experience from past disasters has shown that businesses will move or fail if services cannot be restored in one month; so Oregon faces a very real threat of permanent population loss and long-term economic decline.

We cannot avoid the future earthquake, but we can choose either a future in which the earthquake results in grim damage and losses and a society diminished for a generation, or a future in which the earthquake is a manageable disaster without lasting impact. We need to start preparing now by assessing the vulnerability of our buildings, lifelines, and social systems, and then developing and implementing a sustained program of replacement, retrofit, and redesign to make Oregon resilient to the next great earthquake. We know how to engineer buildings, roads, and power lines to withstand this earthquake; the hard part will be to find the will, commitment, and persistence needed to transform our state.

The Oregon legislature recognized the scale of this problem when it passed House Resolution 3 in 2011 (see Appendix I for details of House Resolution 3), noting the likely impact of a Cascadia earthquake and the need for a plan to move the state towards resilience to that event. The Oregon Seismic Safety Policy Advisory Commission (OSSPAC) was charged with developing a resilience plan, which is described in this report. The report summarizes the science of Cascadia subduction zone earthquakes and estimates their impacts; it then provides detailed analysis of the current vulnerability of our buildings and business community, and our transportation, energy, communication, and water/wastewater systems. The report defines the performance targets that each sector must meet to achieve adequate resilience, and provides detailed recommendations for the actions required to meet those targets over the next 50 years.

## How OSSPAC Developed This Plan

House Resolution 3 passed by the 2011 legislature directed OSSPAC to “lead and coordinate preparation of an Oregon Resilience Plan that reviews policy options, summarizes relevant reports and studies by state agencies and makes recommendations on policy direction to protect lives and keep commerce

flowing during and after a Cascadia earthquake and tsunami”. To meet this challenge OSSPAC first defined what resilience would mean for Oregon:

*Oregon citizens will not only be protected from life-threatening physical harm, but because of risk reduction measures and pre-disaster planning, communities will recover more quickly and with less continuing vulnerability following a Cascadia subduction zone earthquake and tsunami.*

OSSPAC identified existing and ongoing earthquake resilience planning from San Francisco, California (SPUR, 2009) and the State of Washington (Washington Seismic Safety Committee, 2012) as good models to follow. These studies outlined an approach that included estimating the current earthquake vulnerability of systems and structures, defining the performance standards that structures and systems would need to meet over fifty years in order to be sufficiently resilient, and then identifying changes in practice and policy that would help attain those performance standards. One difference for the Oregon Resilience Plan was that it needed to encompass the entire state unlike the City of San Francisco study, and that it focused on the Cascadia earthquake threat, unlike the Washington study which considered multiple earthquake scenarios.

To complete the plan without funding and on a one-year schedule, OSSPAC chose to tap into volunteer expertise from Oregon’s academic, professional, governmental and public communities. Over one hundred volunteer experts drawn from a broad section of Oregon society were organized into eight work groups to survey the following parts of the problem:

- Cascadia Earthquake Scenario
- Business and Workforce
- Coastal Communities
- Critical and Essential Buildings
- Energy
- Transportation
- Information and Communications
- Water and Wastewater

The purpose of the task group assigned to the Cascadia Earthquake Scenario was to develop a detailed description of the likely physical effects throughout Oregon of a major Cascadia subduction earthquake so that the other groups could assess the impact on their respective sectors. Each of the remaining seven groups focused on one of the sectors of society or parts of the built environment listed above. The Coastal Task Group was included to recognize the unique risk along the coast: this region will experience a combination of tsunami damage and damage from extreme shaking.

Each group was charged with three primary tasks: First, determine the likely impact of the scenario earthquake on the assigned sector and estimate the time required to restore functions in that sector if

the earthquake were to happen under current conditions. Second, define performance targets for the sector. The targets represent the desired timeframes for restoring functions in a future Cascadia earthquake—in other words, the timeframes within which functions must be restored if Oregon is to be resilient. Finally, provide a series of recommendations to OSSPAC for changes in practice and policy that, if implemented, would ensure that Oregon reaches the desired resilience targets over the next 50 years.

The products from the various task groups were reviewed by an advisory group of subject matter experts to ensure that the material was accurate, complete, and up-to-date. OSSPAC then reviewed the recommendations and selected and endorsed those that the commission felt offered the most effective way to achieve resilience to a great Cascadia disaster.

## **Great Earthquakes on the Cascadia Subduction Zone**

For the last twenty-five years, the scientific community has been aware of the possibility that a great earthquake caused by the Cascadia subduction zone could strike the Pacific Northwest. Now, after decades of research and recent great earthquakes in Sumatra, Chile, and Japan, awareness of this threat is widespread in Oregon, and we know enough to paint a picture of what Oregon might look like after such an earthquake. Oregon is a geologic mirror image of northern Japan (see Figure 1.1). In both places, the Pacific Ocean floor is sliding beneath the adjacent continents along giant faults called subduction zones. The scientific understanding of the Cascadia threat makes it clear that very large earthquakes will occur in Oregon’s future, and that our societal and physical structures are poorly prepared to meet the threat unless we take action now to start building the necessary resilience.

## **What Are Subduction Zone Earthquakes?**

The surface of the earth is broken into dozens of tectonic plates—continent-sized slabs of rigid rock that slowly slide across the more pliant mantle of the earth beneath. Moving at speeds of a few inches per year, the plates can pull apart, slide past each other, or collide head on. Where an oceanic and a continental plate collide, a subduction zone forms, as one plate is forced beneath the other, deep into the softer rock of the mantle. A great arc of subduction zones surrounds the Pacific Ocean, producing what geologists call the “Ring of Fire.” In Japan, the ocean floor of the Pacific Plate moves towards the west, sliding beneath the Eurasian Plate that supports the islands of Japan. The Pacific Northwest is a geologic mirror image of Japan, with the Pacific Ocean floor moving towards the east, sliding beneath Oregon, Washington, and Northern California along a 600-mile fault called the Cascadia subduction zone.

In Japan, there has never been any doubt that great subduction earthquakes are possible: Japan’s long written history has recorded many such events, with the 2011 Tohoku earthquake being the most recent and one of the most powerful and destructive. In that earthquake, a section of the Pacific Ocean floor measuring 300 miles long and 125 miles wide lurched as much as 100 feet down the subduction zone, causing a great magnitude 9.0 earthquake. The eastern edge of the Eurasian Plate, which had been slowly bending for centuries under the relentless pressure of subduction, snapped back during the

earthquake, displacing trillions of tons of seawater and triggering a catastrophic tsunami. The release of the bent Eurasian Plate caused land along the coast of Japan to permanently sink several feet, and the strong shaking from the earthquake caused widespread landslides on steep slopes (both on land and undersea) and widespread liquefaction of soft sediments on land.

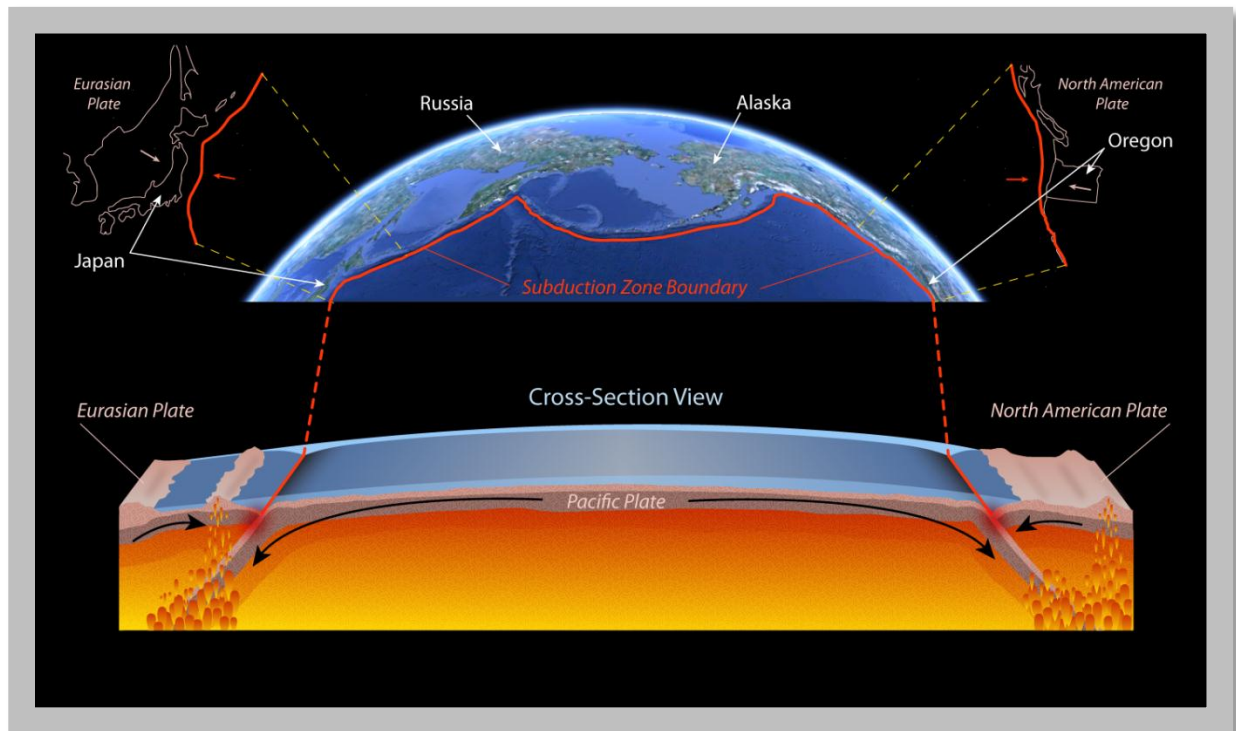


Figure 1.1: Oregon is a geologic mirror-image of Northern Japan. In both places, the Pacific Ocean floor is sliding beneath the adjacent continents along giant faults called subduction zones (Source: Graphic by Dan Coe, DOGAMI).

In 1984, when seismologists first proposed that Cascadia might produce similar earthquakes, there was considerable doubt. Research since then has confirmed that Cascadia has a long history of great subduction earthquakes and that energy for the next great earthquake is currently building along the fault. Geologic studies (see Figure 1.2) have uncovered evidence of the coastal subsidence, tsunamis, landslides, and liquefaction that were produced by past Cascadia earthquakes, and ultra-sensitive GPS measurements show that the Oregon coast is moving eastward a few inches per year along with the Pacific Ocean floor, motion that will be abruptly reversed during the next great subduction earthquake. There is no scientific doubt that another great subduction earthquake will strike the Pacific Northwest; the questions now are how soon, how large, and how destructive that earthquake will be.

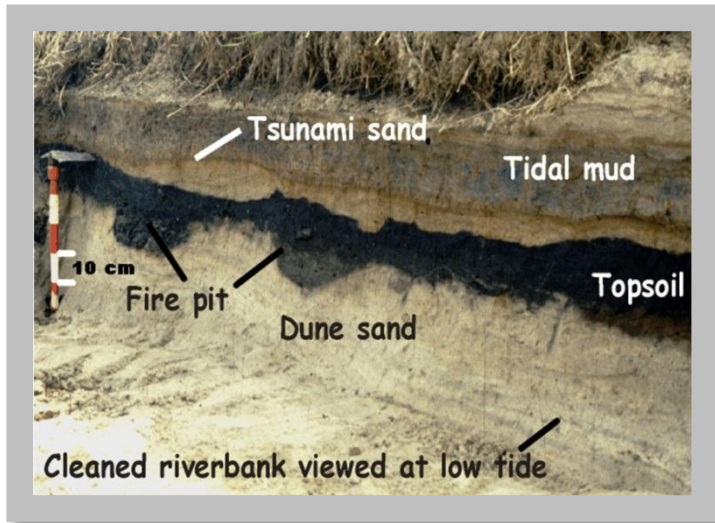


Figure 1.2: This photo (Source: Brian Atwater, USGS) shows a riverbank from the Salmon River estuary where Native American firepots were found in a forest soil that subsided in the 1700 AD earthquake and was buried by tsunami sand and tidal mud.

Geologists have assembled a ten thousand year record of past Cascadia earthquakes (see Figure 1.3) by studying sediments in coastal marshes and on the ocean floor. This record shows that past earthquakes have occurred at highly variable intervals and can range widely in size and in which parts of the Pacific Northwest they affect. About half of the past earthquakes have been very large (estimated magnitude 8.3 to 8.6) and centered on the southern Oregon coast, while the other half have been great (estimated magnitude 8.7 to 9.3) and extending from northern California to British Columbia. The most recent event occurred on January 26, 1700 AD, and was a great earthquake with a magnitude of 9.0. The time interval between previous earthquakes has varied from a few decades to many centuries, but most of the past intervals have been shorter than the 313 years since the last event. It is simply not scientifically feasible to predict, or even estimate, when the next Cascadia earthquake will occur, but the calculated odds that a Cascadia earthquake will occur in the next 50 years range from 7-15 percent for a great earthquake affecting the entire Pacific Northwest to about 37 percent for a very large earthquake affecting southern Oregon and northern California. The likelihood of a M 9 Cascadia earthquake during our lifetimes and the consequences of such an earthquake are both so great that it is prudent to consider this type of earthquake when designing new structures or retrofit of existing structures, evaluating the seismic safety of existing structures, or planning emergency response and preparedness.

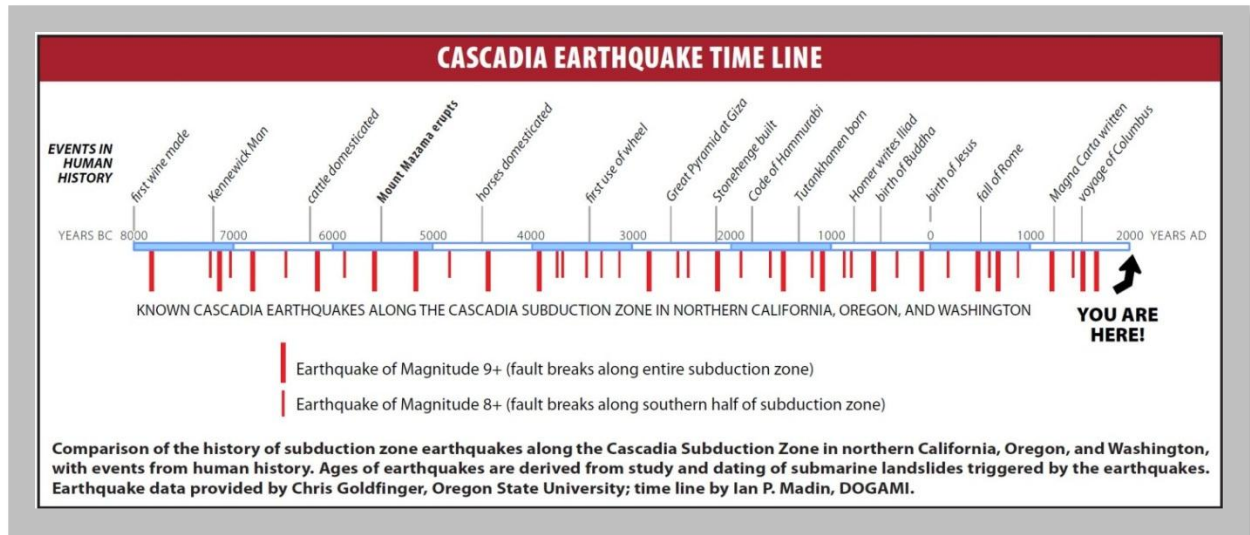


Figure 1.3: This timeline compares the 10,000-year-long history of Cascadia earthquakes to events in human history.

## Resilience Plan Earthquake Scenario

For the purpose of this resilience planning effort, we chose to look at the effects of a great earthquake of magnitude 9.0, because it is a very real possibility that would affect all of Oregon and is directly comparable to the 2011 Tohoku earthquake, the effects of which are all too well known. Using the latest models from the United States Geological Survey (USGS), we simulated the strong shaking that is likely to occur during the region's next magnitude 9.0 event. The simulated shaking map was then used to estimate the amount of ground failure due to liquefaction and landsliding that would result from such an earthquake. For the tsunami, we used a model of the inundation from a magnitude 9.0 event. This model, which was produced by the Oregon Department of Geology and Mineral Industries (DOGAMI), was applied to maps of the coast to show which areas and facilities would be inundated. The tsunami models also provided estimates of the permanent coastal subsidence that would accompany the earthquake and tsunami. These maps of simulated earthquake effects were used to evaluate the likely performance of Oregon's critical buildings and infrastructure.

The simulation shows that Oregon would experience shaking very similar to the shaking that northern Japan endured in 2011. As indicated in Figure 1.4, areas along Oregon's coast would experience severe to violent shaking, while cities along the I-5 corridor would experience strong or very strong shaking. East of the Cascades, shaking would be light to moderate. In all areas, the strong shaking would last from two to four minutes.

This expected pattern of damage led OSSPAC to evaluate the state in four distinct zones (see Figure 1.5):

- The Tsunami Zone, where severe shaking and tsunami inundation would cause near total damage, and threaten the lives of thousands of residents.



- The Coastal Zone, where severe shaking and damage to transportation systems would severely disrupt and isolate communities and where the major challenge after the earthquake would be to keep the population sheltered, fed and healthy.
- The Valley Zone, where widespread moderate damage would severely disrupt daily life and commerce and where restoring services to business and residents would be the main priority.
- The Eastern zone where light damage would allow rapid restoration of services and functions, and where communities would become critical hubs for the movement of response recovery and restoration personnel and materials for the rest of the state.

The results of the ground failure simulation (see Figure 1.6) suggest that large areas of western Oregon would be severely affected. Strong shaking causes ground failure in two ways. Along rivers, lakes, and the coast, where there are deposits of loose water-saturated sand, shaking causes the sand to liquefy, and the weakened soil readily settles or spreads. On steep slopes with weak soil and rock, or in areas of existing landslides, the shaking can cause new or renewed landslide movement, with very damaging results. Ground failure can cause severe damage to buildings and is particularly damaging to lifelines, which by their nature must often cross wide areas of affected ground.

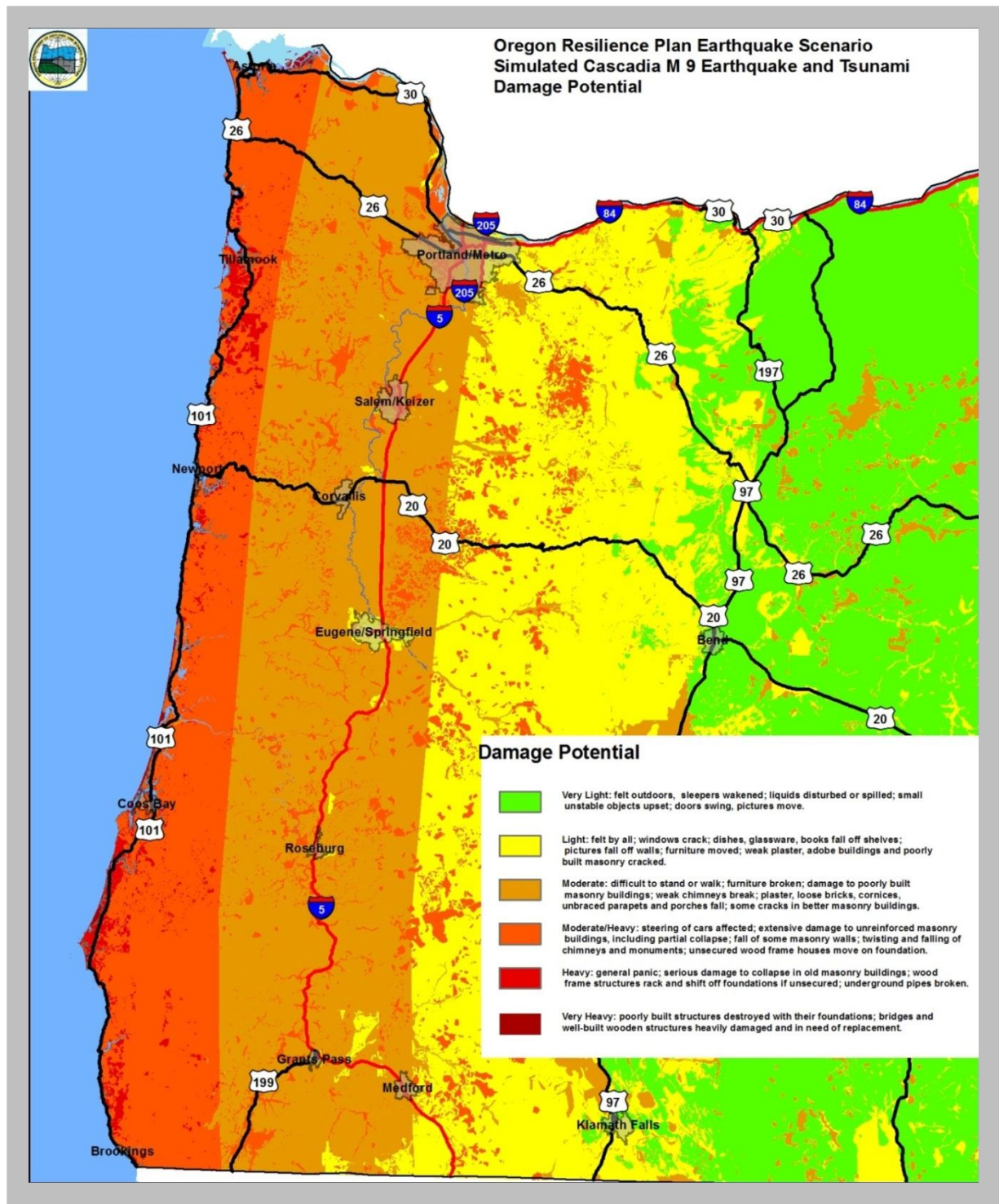


Figure 1.4: Simulated shaking for the magnitude 9.0 Cascadia scenario.



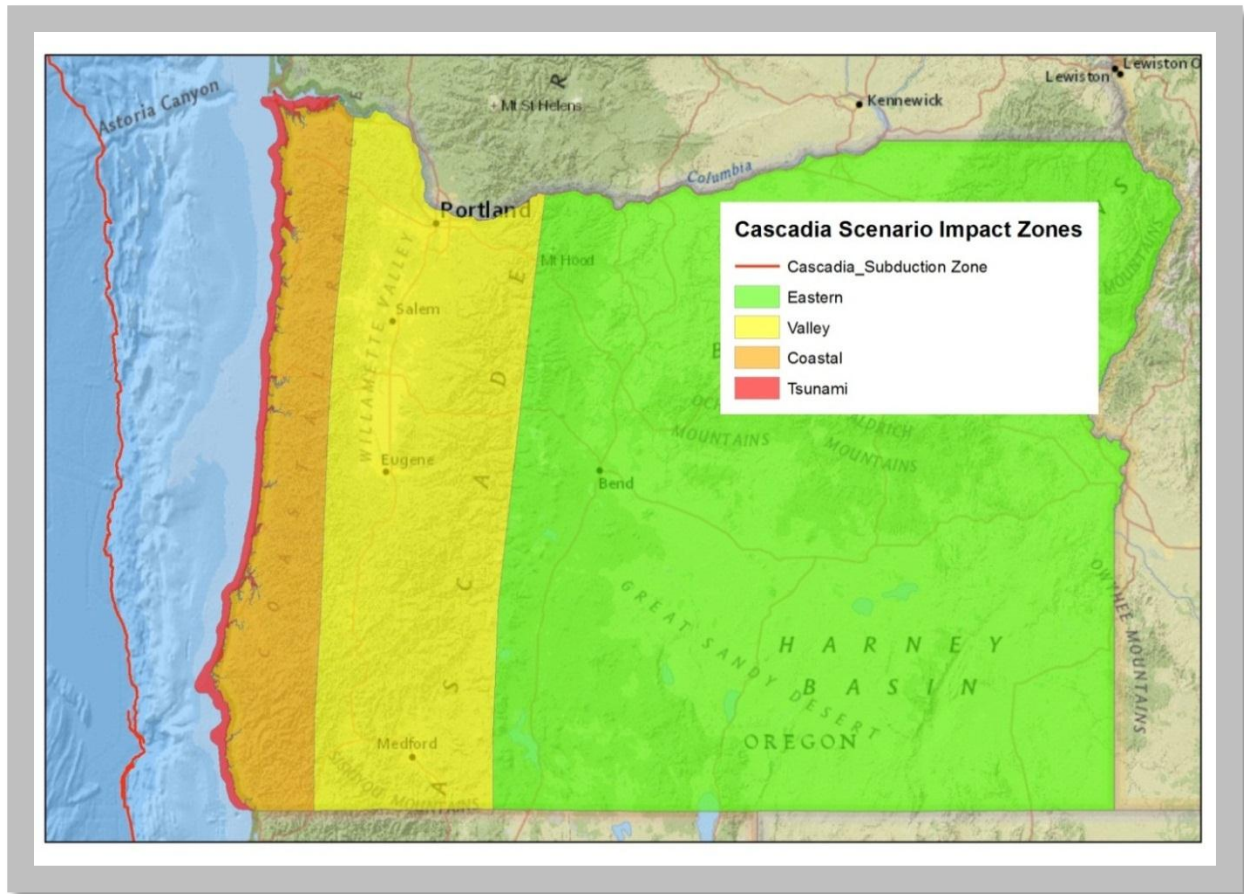


Figure 1.5: Impact zones for the magnitude 9.0 Cascadia earthquake scenario. Damage will be extreme in the Tsunami zone, heavy in the Coastal zone, moderate in the Valley zone, and light in the Eastern zone.

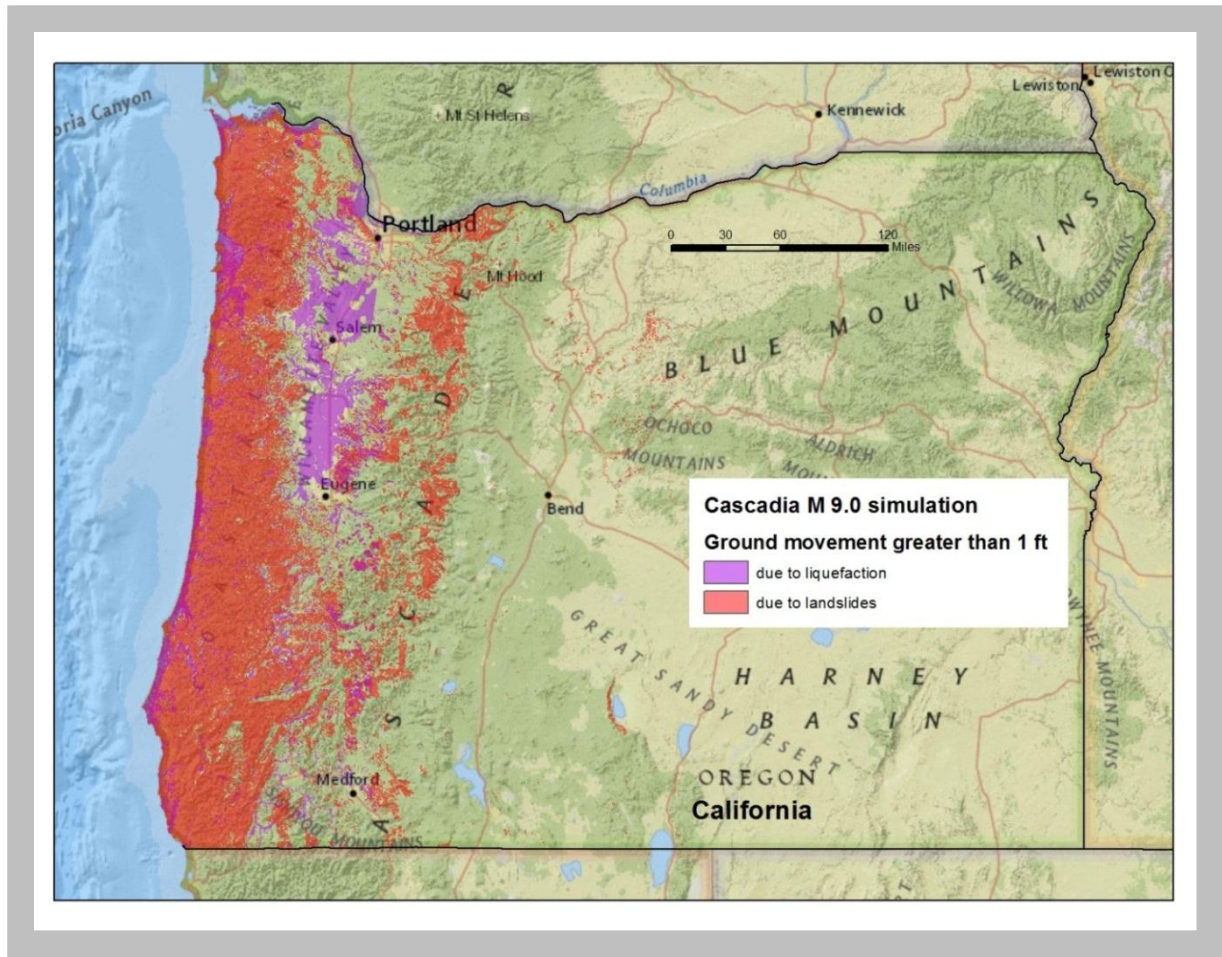


Figure 1.6: Ground failure and movement for the magnitude 9.0 Cascadia earthquake scenario. Colored areas could experience more than one foot of ground movement due to earthquake-induced landslides in steep areas and liquefaction failure in lowlands. Both forms of ground failure can cause severe damage.

The amount of tsunami inundation that would be experienced along the coast due to the scenario magnitude 9.0 earthquake is quite variable and depends on local topography. Large parts of many low-lying communities, such as Warrenton, Seaside, Rockaway Beach, and Neskowin (see Figure 1.7), will be inundated.





Figure 1.7: Estimated inundation of Neskowin due to the tsunami from the scenario magnitude 9.0 Cascadia earthquake. This tsunami map is based on the SB 379 regulatory inundation line.

The same large scale bending of the tectonic plates that causes the tsunami will also cause immediate and permanent subsidence in many parts of the coast. As indicated in Figure 1.8, the amount that the land will drop varies from place to place, with as much as 5 to 6 feet possible near Astoria, and even more possible at Brookings.

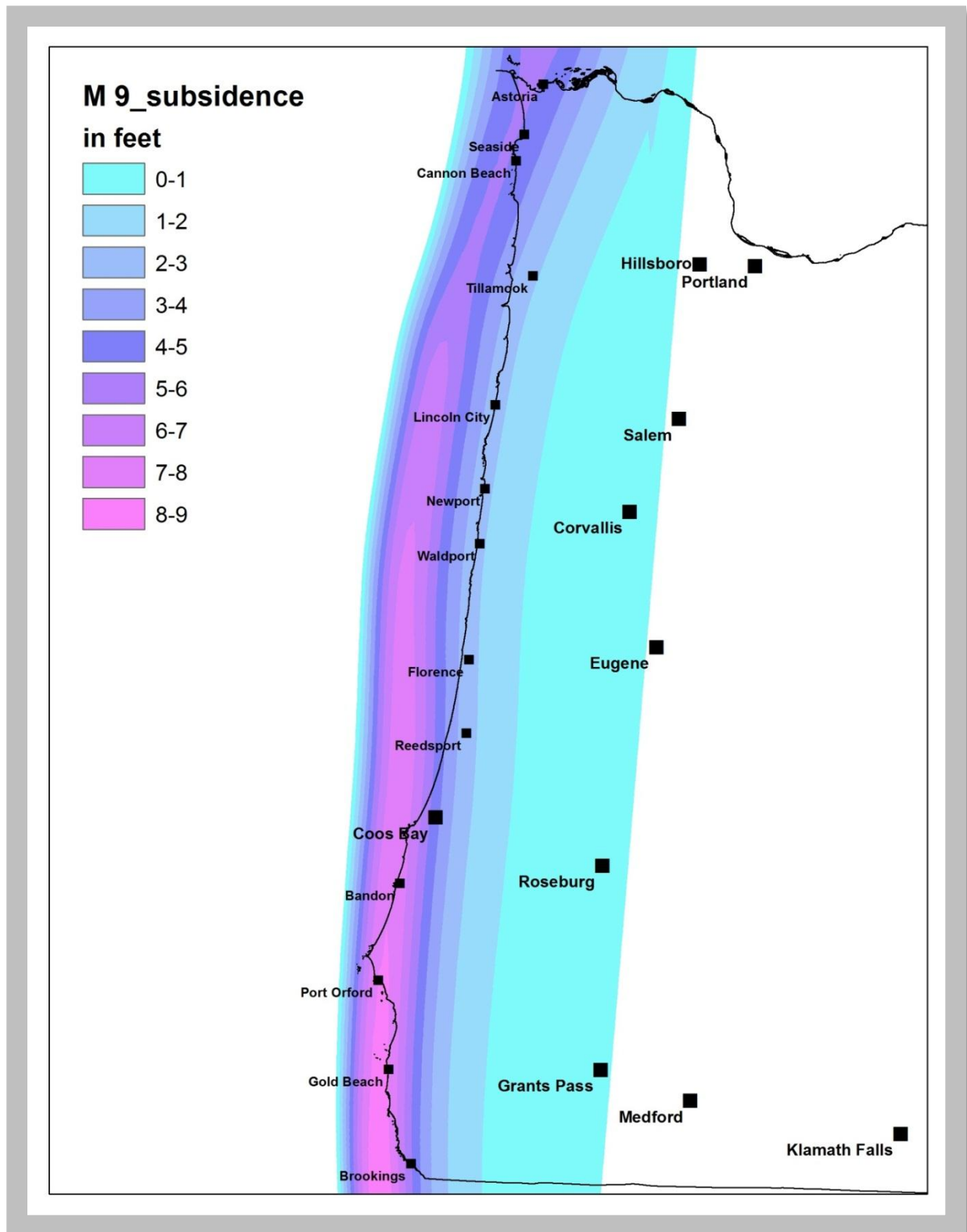


Figure 1.8: Estimated permanent land subsidence from the scenario magnitude 9.0 earthquake for the Oregon Coast. Subsidence would occur during the earthquake.

## Oregon’s Infrastructure and Risk

The estimated impacts of a Cascadia subduction earthquake in Oregon are catastrophic. This is partly due to the sheer size and power of a magnitude 9.0 earthquake, but it is also the result of the inherent vulnerability of our buildings and lifelines. In 1974, Oregon adopted a statewide building code that mandated some seismic resistance for new construction. Prior to that date, the majority of buildings in Oregon had been designed without regard to earthquake forces. In 1993, Oregon’s building codes were changed to require designs that would accommodate shaking from a Cascadia subduction zone earthquake, almost doubling the earthquake forces used in earlier codes. This means that the majority of buildings in Oregon have not been designed to resist the shaking from a magnitude 9.0 Cascadia earthquake. This widespread vulnerability of Oregon’s buildings is grimly illustrated in the *Statewide Seismic Needs Assessment* completed by the Oregon Department of Geology and Mineral Industries (DOGAMI) in 2007. This study surveyed public schools and public safety buildings (police and fire stations, hospitals, and emergency operation centers) in Oregon and assessed their potential for collapse in a major earthquake. Almost half of the 2,193 public school buildings examined had a high or very high potential for collapse, as did almost a quarter of the public safety buildings. Of the 2,567 highway bridges in the Oregon Department of Transportation (ODOT) system, 982 were built without seismic considerations, and of the rest, only 409 were designed specifically with consideration of Cascadia subduction zone earthquakes. The list goes on: old, brittle iron water pipes in the Portland water system, century-old bridges over the Willamette River, and highways and power transmission lines that traverse landslide-prone terrain. The core of our vulnerability to a Cascadia earthquake is not the earthquake alone, but the inadequacy of our built environment.

The experience of the Tohoku earthquake shows that few structures are likely to survive in the tsunami inundation zone. In Oregon, the USGS estimates that almost 1,900 businesses employing nearly 15,000 people are located in the scenario inundation zone. The inundation zone also contains almost 10,500 housing units with a total population of just over 22,000. This exposure to the extreme hazard posed by the tsunami is unavoidable.

Another major factor that amplifies the effects of a Cascadia earthquake is the interdependency of our lifeline systems, coupled with the wide geographic spread of a Cascadia disaster. Unlike a severe storm, a Cascadia subduction earthquake would simultaneously damage power, natural gas, and petroleum lines, roads and bridges, water and sewer systems, critical buildings, and communications over large parts of three states (i.e., California, Oregon and Washington). Restoration of communication service would require that electric power be restored, which would require that roads and bridges be repaired, which in turn would require that the petroleum delivery and distribution system be repaired. These interdependencies between lifeline systems would be made even more difficult by the broad geographic extent of the damage. The nearest undamaged urban areas from which assistance could be organized would be Spokane, Washington, Boise, Idaho, and Redding, California. Virtually all of the resources required for the recovery of lifeline systems would have to come from outside the affected states.



## Estimated Impacts

The scenario Cascadia earthquake would be an unprecedented catastrophe for Oregon and for the United States. It would impact every aspect of life for all Oregonians and for the residents of northern California, Washington, and British Columbia. The effects of a Cascadia subduction earthquake will be greatest on the coast, which is right next to the subduction zone fault, and will diminish as one goes inland. This, in combination with Oregon’s mountainous geography, divides the state into four impact zones: within the tsunami zone, damage will be nearly complete. In the coastal zone, shaking will be severe, liquefaction and landsliding will be widespread and severe, and damage will be severe. In the valley zone, shaking will be strong, liquefaction and landsliding will be common but less severe, and moderate damage will be widespread. In the eastern zone, shaking will be mild, landslides and liquefaction sporadic, and damage generally light.

The impacts of a great subduction earthquake on Oregon are impossible to predict accurately, but several studies have estimated damage and casualties, and those estimates give a sense for how far-reaching a disaster the next great earthquake will be. Estimated consequences include:

- Earthquake deaths ranging from 650 to 5,000, with another 600 to 5,000 deaths due to the tsunami.
- 24,000 buildings completely destroyed, and another 85,000 with extensive damage requiring months to years of repair.
- Approximately \$32 billion in economic losses.
- 27,600 displaced households.
- Almost 10 million tons of debris (1 million dump truck loads).

These high levels of damage and loss reflect both the great size of the earthquake and the fact that many buildings, roads, bridges, and utility networks were designed before Oregon’s building codes and practices recognized any significant earthquake threats, and most were designed before codes began to take great subduction earthquakes into account. Lifeline systems, such as highways and pipelines, are particularly vulnerable to ground failure, which will be widespread in the next great earthquake. As a result, the vulnerability analyses done for this plan are grim. For example, if the earthquake were to happen tomorrow, the estimated time to restore function would be:

- One to three years to restore drinking water and sewer service in the coastal zone.
- One month to one year to restore water and sewer in the valley zone.
- Six to twelve months to restore partial function of the top-priority highways in the valley zone.
- Two to four months to restore police and fire stations in the valley zone.
- Eighteen months to restore healthcare facilities in the valley zone, three years or more in the coastal zone.

- One to three months to restore electricity service in the valley zone.
- Three to six months to restore electricity service in the coastal zone.

These estimates of the time it will take to restore the functions necessary to maintain our population and economy are sobering, particularly when coupled with the likelihood that businesses will start to leave the state if services are not restored within one month. If we pursue a policy of “business as usual,” our future after the next Cascadia earthquake will include decades-worth of declining economy and population. We can only avoid this future and achieve resilience by starting now on a sustained program to reduce our vulnerability and decrease our recovery time before the next earthquake inevitably occurs.



## Recommendations

The Cascadia Scenario workgroup prepared a description of the likely effects of a magnitude 9 subduction earthquake for the other workgroups to use in their evaluations. The scenario used the best currently available data, and well-established methods, but still provides an estimate that has a lot of uncertainty and little detail. For an improved understanding of the threat posed by Cascadia earthquakes, we recommend that the state:

- ▶ Support Oregon universities and state agencies to carry out research into the effects of future Cascadia subduction earthquakes and tsunamis on Oregon's landscape, population, buildings and lifelines;
- ▶ Support Oregon universities and state agencies in preparing more detailed and accurate estimates of damage and loss in Oregon from future Cascadia subduction earthquakes and tsunamis; and
- ▶ Provide ready access to the best available Cascadia earthquake information for emergency responders and planners, architects and engineers, and the general public.
- ▶ In order to ensure that design of future structures, retrofit of existing structures, seismic vulnerability evaluations and preparedness planning will provide adequate resilience, we also recommend that all of these efforts use, as a minimum, the ground motion parameters provided by the most current version of the International Building Code, which reflect the most current USGS seismic hazard maps.

## Reference

1. DOGAMI (2007), *Statewide Seismic Needs Assessment Using Rapid Visual Screening (RVS)*. For detailed information, see <http://www.oregongeology.com/sub/projects/rvs/default.htm#overview>
2. Oregon Department of Transportation (2009), *Seismic Vulnerability of Oregon State Highway Bridges: Mitigation Strategies to Reduce Major Mobility Risks*. For detailed information, see [ftp://ftp.odot.state.or.us/Bridge/bridge\\_website\\_chittirat/2009\\_Seismic\\_Vulnerability\\_final.pdf](ftp://ftp.odot.state.or.us/Bridge/bridge_website_chittirat/2009_Seismic_Vulnerability_final.pdf).
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4. Washington Seismic Safety Committee (2012). *Resilient Washington State: A Framework for Minimizing Loss and Improving Statewide Recovery after an Earthquake*. November. See <http://www.emd.wa.gov/about/SeismicSafetyCommittee.shtml>